Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)

doi:10.36487/ACG_repo/2315_081

Closure cost estimate—an approach to estimate productivities of main closure activities

JM Espezúa *SRK Consulting (Peru), Perú*

EL Vasquez *SRK Consulting (Peru), Perú*

Abstract

Peru's mining tradition dates back centuries. In recent decades, the presence of leading international companies has made Peru the world's second largest producer of silver, copper and zinc and the first producer of gold, zinc, tin, lead and molybdenum in Latin America. Currently, mining legislation and mining companies contemplate standards to ensure sustainable mine closure and adequate treatments of mining environmental liabilities.

To date, experience with mine closure has been limited. Cost estimates for these operations focus on meeting two objectives: estimating the amount of the guarantee that will be granted to the regulatory body and estimating the costs that the mine operator expects to incur based on the current mine plan and until the end of the mine's life.

Mine title holders report significant differences in the cost estimates made by consultants for project engineering and the real costs incurred during closure. Even when the input information for estimation purposes is the same, this difference exceeds expected accuracy ranges for the level of engineering developed. Our working hypothesis is that this difference is attributable to the method used to calculate closure cost estimates.

In Peru, as is the case throughout South America, the unit price analysis method (UPA) has rendered good results when estimating the costs of construction projects in general. In these cases, calculations are developed in greenfield environments with multiple and varied work fronts and activities can be carried out simultaneously and independently of each other, which gives the contractor sufficient flexibility to easily reassign the workforce and redeploy construction equipment. In the aforementioned scenarios, UPAs treat activities as separate event when calculating productivities, as befits a greenfield environment.

Due to their nature, mine closure works will be carried out in a brownfield environment, particularly in progressive closure phase, where aspects of mining production activities run alongside closure activities that entail work on specific components (Pit, Pad, waste dump, tailings dam, haul road, etc.). In this scenario, unlike the greenfield environment described above, dissimilarity in activities on different work fronts means that little flexibility exists to reassign labor and construction equipment. As such, it is important to evaluate the interaction between activities in the construction process and their impact on the productivity of construction teams and labor crews.

Mine closure activities can be grouped into three broad groups for direct costs:

- Earthwork costs associated with rehabilitating all disturbed footprints and for earthwork maintenance and repair during the post-closure period *as the remediated site stabilizes.*
- *Decommissioning, remediation, and demolition costs to dismantle, remove, and dispose of all off-site infrastructure.*
- *Water management infrastructure costs.*

In this document, we use real data from a local experience for haul road closures. We propose an alternative method to estimate closure costs for an earthmoving group that contemplates a base work crew and base *construction equipment to calculate key productivity, which in turn conditions the productivity of related activities in the work schedule and construction process.*

The result obtained using the alternative method is within the range of the differences currently found by mining title holders when comparing results for closure estimates made in the study phase versus real costs. The application of this methodology could serve as a reference point for owners and consultants, who must make adjustments to suit varying circumstances.

This work does not purport to define best practice within any particular jurisdiction or mining operation.

Keywords: *closure cost estimates, key productivity, daily rates*

1 Introduction

Peru's mining history dates back centuries but the presence of leading international companies has made Peru the world's second largest producer of silver, copper, and zinc worldwide and the top producer of gold, zinc, tin, lead and molybdenum in Latin America. Today, both legislation in mining countries and the standards utilized by mining companies aim to guarantee sustainable closure of mines and adequate treatment of mining environmental liabilities.

In Peru, some mining projects have begun progressive closure works on some components. In accordance with the regulations, these mines, which are nearing the end of the end of life, are preparing detailed closure engineering studies for construction. Even at same level of engineering, significant differences are evident between the closure cost estimates developed by consultants as a reference for budgeting purposes versus the estimates made by those who will execute closure works.

In Peru, estimates of direct costs for mine closure are currently calculated with unit price analysis (UPA), which consists of disaggregating the cost per unit of measurement for each component (assembly) expressed in $/m^3, $ton, $m^2 etc.; identifying productivities, costs and quantities of each of the inputs and materials to be used; and establishing said costs for the different assembly components such as: materials, manual labor, construction equipment required based the technical specifications of the contract given that the activities is executed in isolation and entails no interaction with other closure activities.

Assemblies constitute the minimum construction units into which a work, project or budget can be divided. Generally, they have a code, description, and unit of measure. The accuracy of the estimate of the cost of a project will depend on the number of assemblies specified or into which a project can be disaggregated. It is evident schematics or generic drawings at a conceptual engineering level will be insufficient to disaggregate into assemblies that adequately represent the construction process; to counter this, allowances must be included. The impact that said allowances will have on costs will be determined in part by the experience of the cost estimator, which generates significant bias in the estimate result.

The cost calculated by multiplying a quantity by a unit price for a certain assembly fails to take the project schedule and the timing of its execution into account and assumes that the activity will be carried out in isolation and that all resources are available and will stop working once a specific quantity of work is completed. For example, if the analysis of unit prices contemplates the use of six people and three units of construction equipment, and considers the amount of work required for said activity and the expected productivity of the same, only five hours of work are required in an eight-hour shift; the UPA assumes that the contractor has the ability to immediately redeploy all of the resources in question to another task. In construction, teams and equipment cannot always be relocated. In general, construction contractors mobilize a complete crew of people and construction equipment to the site knowing that some resources may not be used over 100% of the project's hours. To handle this situation, contractors utilize "all-in" rates and productivities that are adjusted for shift hours rather than unit prices per unit of work.

The difference in the cost estimate methodologies utilized by consultants and contractors may be driving the significant differences noted in closure cost estimates. In this document, we present some guidelines for estimating closure costs that allow both consultants and contractors to obtain similar accuracy in their estimates, understanding accuracy as the difference between the real cost obtained when executing the project versus the estimated cost in a referential way.

2 Methodology

In this section, we present a cost estimate method that focuses on reproducing the logic that a project contractor would use to execute closure works. In this scenario, the contractor is aware that the nature of the activities at hand will make it difficult to efficiently use labor or construction equipment given that productivities for a number of resources will need to be adjusted to contemplate the productivity of key activities in the critical path for closure works.

Accepting the premise that mine closure activities can be grouped into three large groups for direct costs:

- Earthwork costs associated with rehabilitating all disturbed footprints and for earthwork maintenance and repair during the post-closure period as the remediated site stabilizes.
- Decommissioning, remediation, and demolition costs to dismantle, remove, and dispose of all off-site infrastructure.
- Water management infrastructure costs.

To estimate costs for each group, the following steps are proposed:

1. Identifying activities and their sequence in the construction process. With support from engineering drawings and technical specifications, all activities necessary to complete the task should be listed.
2. Identifying the critical path. These activities are linked to each other given that some necessarily precede others. For example, if a pit must be filled with borrow material (in the earthmoving group), loading and hauling operations cannot be conducted if material has not been cut prior to transport and a disposal area has not been previously prepared.
3. Identifying the key activity and key productivity. Each of the previously identified activities requires specific construction equipment, labor and material resources; by their very nature, each activity has different productivities if executed separately but the productivity of each will be key to determining the resources necessary to engage in other activities. Using the previous example of filling a pit, given topographic conditions, only a Cat D-8 dozer can be used to distribute borrowed material; as such, construction equipment for loading and transporting the material must be sized for the key productivity that corresponds to a Cat D-8 dozer and as such, some loading or transport construction equipment may be underutilized.
4. Definition of the base components and rate per day. Once the key productivity– and consequently the resources required for other related activities– has been defined, the base components necessary to complete the task for each group is built. These base components will be comprised of materials, labor, and construction equipment, which contemplate a variety of wage and rate categories. As such, a daily rate will be calculated for use in the estimates.

3 Data

To illustrate the proposed methodology, we will use an example of a haul road closure in the Peruvian mountains 3,700 meters above sea level. Typically, the closure engineering design for this type of work proposes rehabilitating a section of the haul road to recover the natural slope of the environment. This entails cut and compensated filling methods to ensure the site recovers the characteristics it had prior to the haul road's construction.

Figure 1 depicts an average point of reference for the procedure to rehabilitate a haul road solely within a context of earth movement activities; no demolition work is required and the scheme does not include water management activities. Technical specifications at the engineering level indicate that some unsuitable material (contaminated) exists in the cut area. This material is not apt for use as fill and must be transported to material dump located at a given distance. Accordingly, it will be necessary to import borrow material from a quarry with suitable material– which is also located at a distance– to offset the material exported from the area. Once a stable slope is established, it will be necessary to lay topsoil and initiate a revegetation process with native species to reclaim the characteristics of the primary environment.

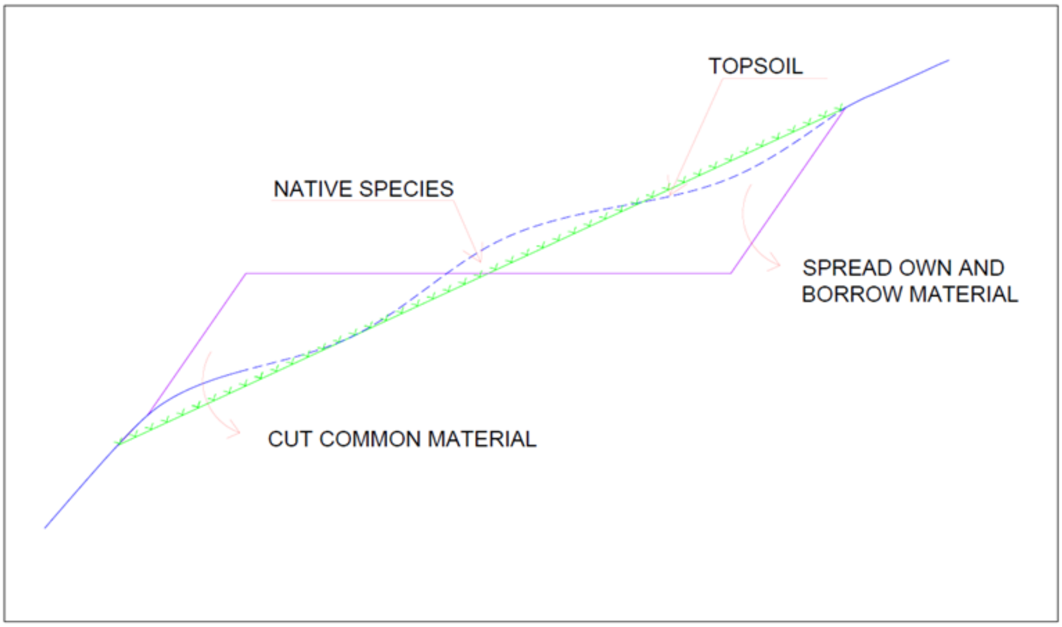

Figure 1 Earthwork scheme in haul road section

In our example, the haul road to be rehabilitated has an area of 367,065 m², which must be cleared prior to subsequent activities. Drawings indicate that the quantity of material to be cut on the slope totals 196,800 m^3 while the unsuitable material that must be eliminated totals 81,064 m^3; the same quantity of material must be imported and the distances between centres of gravity to the waste dump, the borrow quarry and the topsoil deposit are 3 km, 4.0 km and 2.5 km respectively.

With this basic information, we proceed to develop the proposed methodology.

3.1 Identification of activities and their sequence in the construction process

The following table presents the list of individual activities, the amount of terrain to be covered, and units of measure, obtained from the drawings and in accordance with the technical specifications of the project, assuming that all materials are available in sufficient quantities to execute the work.

Table 1 List of activities for the rehabilitation of a haul road

Item	Activity	Unit	Qty
1.01	Cut (common material)	m^3	196,800
1.02	Spread own material	m^3	189,149
1.03	Excavation borrow material	m^3	81,064
1.04	Load borrow material	m^3	81,064
1.05	Haul borrow material d= 4 km	m^3	81,064
1.06	Spread borrow material	m^3	81,064
1.07	Load non competent material	m^3	81,064
1.08	Haul non competent material d= 3 km	m^3	81,064
1.09	Spread on waste dump	m^3	81,064
1.10	Load topsoil	m^3	146,826
1.11	Haul topsoil d= 2.5 km	m^3	146,826
1.12	Spread of topsoil e=0.40 m.	m^3	146,826

According to the closure engineering project, balanced cut and fill will be used. As such, the same volume of earth cut in the lower part of the external slope of the road will be disposed in the upper part, as shown schematically in the following figure.

3.2 Identification of the critical path

The critical path entails fill with own material with a Dozer Cat D-8, followed by the filling with borrow material, which will also be conducted with Dozer Cat D-8. Loading and haul of unsuitable material and its disposal in the waste dump can also be conducted concurrently with the cut and at any point in time using a Cat 330 excavator and 20 m^3 capacity dump trucks.

Another activity that can be conducted concurrently to the fill material is topsoil placement and sowing of native species. This work will be conducted with a Dozer Cat-D6.

Subsequently, an evaluation will be conducted to determine if haul construction equipment is adequate to transport the three types of materials.

3.3 Identification of key activity and productivity

In this case, key activities are those executed with the Dozer Cat D-6 and D-8; therefore, all other activities must be adjusted to align with the productivity of this construction equipment.

The theoretical production of Dozer Cat D-8 that pushes material over an average distance of 60 m is 375 m^3/h, as is evident in Figure 1. Table 2 shows the calculation of the correction factor for this productivity, which considers efficiencies as well as material type; the altitude at which closure works take place; and considering both the cut of the material and the distribution of material will take place on a positive slope from bottom-up. The factor of correction for material distribution is 0.445; as such, corrected production for a Dozer Cat-D8 would be 167 m^3/h (375*0.445), which translates into a production of 1336 m^3 on an 8-hour shift, while the cut would be 186 m^3/h (375*0.495), which translates into a production of 1488 m^3 on an 8-hour shift. We utilize the same method to correct the productivities of the Dozer Cat D-6, whose values are provided in Table 3.

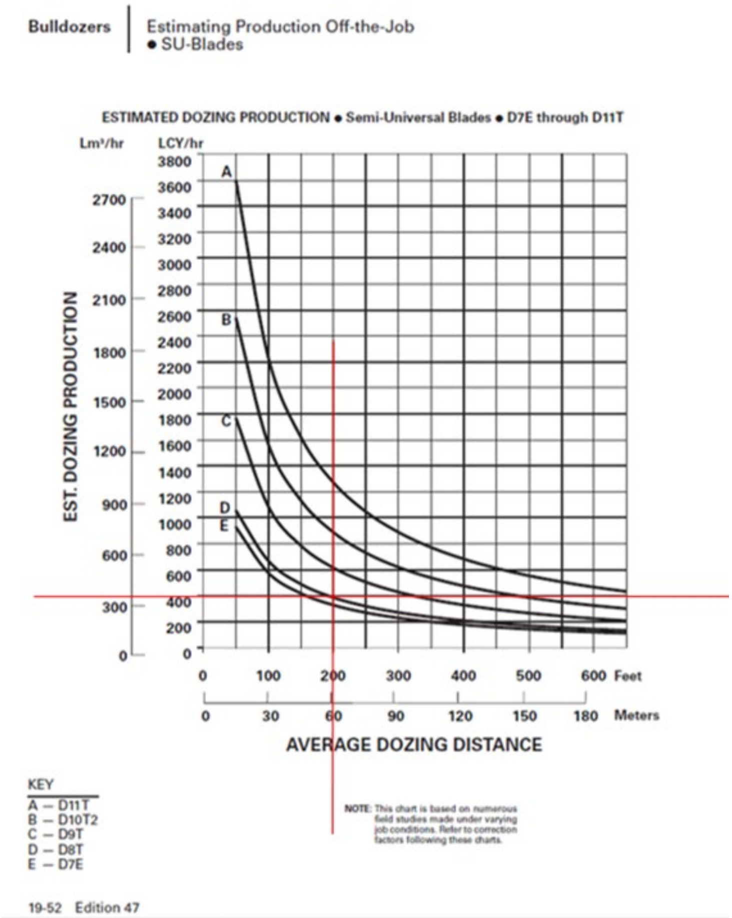

Figure 2 Theoretical productivity (m^3/h) calculated

Table 2 Efficiency applied to calculate correction productivity factor

Description Tipo Mat. (Empuje 60 mt)	Activity Cut	 Spread Material
Operator Capacity	0.75	0.75
Visibility	0.90	0.90
Work efficiency	0.83	0.83
Site altitude	0.93	0.93
Spread	1.00	0.90
Adjustable Blade	0.95	0.95
Correction Factor(m^3/hr)	**0.496**	**0.445**
Productivity Factor (hr/m^3)	2.016	2.247

Table 3 Productivities for key activities

Key Activity	Dozer	Productivity	
Cut	Cat D8	1,488	m^3/day
Spread own material	Cat D8	1,336	m^3/day
Spread borrow material	Cat D8	1,336	m^3/day
Spread topsoil	Cat D6	808	m^3/day
Spread on waste dam	Cat D6	912	m^3/day

The related activities subject to these productivities are loading and transporting the materials to the different destinations. The following table shows the calculation of the 20 m^3 capacity trucks required to transport the materials at the same production rate, it is evident that the loading equipment will be underutilized.

Table 4 Calculation of the number of trucks to transport materials.

Description	Code	Unit	Load & haulage		
			Topsoil	Waste dump	Borrow
Input data					
Average Distance	AD	km	2.5	3	4
CAT 770 Truck	TC	m³	20	20	20
Bucket Capacity CAT336	BC	m³	5.53	5.53	5.53
Truck Loaded Speed	SL	km/h	20	20	20
Truck Unloaded Speed	SU	km/h	25	25	25
Load + Truck Placement Time	LP	min	1.9	1.9	1.9
Wait + Unload Time	WU	min	1.8	1.8	1.8
Calculation					
Travel time Load Truck	TL=60*AD/SL	min	7.5	9	12
Travel time Unload Truck	TU=60*AD/SU	min	6	7.2	9.6
Cycle time	CT=LP+WU+TL+TU	min	17.2	19.9	25.3
Job Efficiency (90% of 8 hours)	JE=90%*8*60	min/day	432	432	432
Number of Trips	NT=JE/CT		25	21	17
Loaded Units	LU=JE/LP	Times	227	227	227
Theoretical number of trucks	TNT=LU/NT	und	9	10	13
Number of Trucks assumed	**NTA=ASSUMED**	**und**	**2**	**3**	**4**
Number of Loads per day	NL=NTA*NT	und	50	63	68
Real Time by Truck	RTT=CT*NT/60	hr	7.2	7	7.2
Real time by load equipment	RTL=LP*NL/60	hr	1.6	2	2.2
Performance Per Shift (8 hours)	**PPS=TC*NT*NTA**	**m³/8hr**	**1,000**	**1,260**	**1,360**
Performance by Hour	PH=PPS/8	m³/hr	125	157.5	170

The "Code" column shows the formulas used to calculate each line. It can be seen that in order to keep the loading equipment (Cat 336 Excavator) occupied 100% of the available time, 14 trucks with a capacity of 20 m^3 would be required to transport borrow material, but to reach the key production of 167 m^3/h, only 4 trucks of 20 m^3 capacity (number of trucks assumed) will be necessary, resulting in the use of only 2.20 hours of loading equipment in an 8-hour shift. In the case of topsoil, it will be necessary to use 2 trucks of 20 m^3 capacity and the excavator will be occupied for only 1.6 hours in the 8-hour shift.

3.4 Definition of the base components and daily rate

Table 5 shows how the number of days required to conduct all related activities to close the haul road is calculated based on the productivities that have been defined as “key.” Nevertheless, the critical path is defined solely by activities to distribute own and borrow material.

Table 5 Calculation of the number of days required to complete the activities

Code	Assembly	Quantity	Unit	m³/day	Days
1.01	Cut	196,800	m^3	1,488	133
1.02	**Spread own material**	**189,149**	**m^3**	**1,336**	**142**
1.03	Load & haul borrow mat.	81,064	m^3	1,336	61
1.04	**Spread borrow mat.**	**81,064**	**m^3**	**1,336**	**61**
1.05	Load & haul exedent mat.	81,064	m^3	912	89
1.06	Spread on waste dump	81,064	m^3	912	89
1.07	Load & haul topsoil.	48,942	m^3	808	61
1.08	Spread of topsoil	48,942	m^3	808	61

The number of days required to carry out the work results from the sum of days of activities on the critical path, that is, 142 days of filling with own material + 61 days of spreading borrowed material, giving a total of 203 useful days to carry out the work.

The other activities have a duration of less than 203 days, therefore they can be carried out concurrently to the activities of the critical path; however, it must be verified if a single team for loading and transporting materials will be enough to handle the transfer of the three types of materials, it is verified that the topsoil that occurs simultaneously with the filling with borrow material will require its own loading and transportation equipment and its own Dozer Cat- D6 for spreading, while the unsuitable material and the borrow material can use the same equipment for load an haul.

The following table shows the quantity of labor and construction equipment that the contractor must mobilize to the work during the 203 days.

Table 6 Base crew of labour and construction equipment for earthmoving group

Crew	Labour	Unit
5	Apprentice	Man Hour
5	Laborers	Man Hour
5	Truck operator	Man Hour
2	Excavator operator	Man Hour
2	Cat d-6 dozer operator	Man Hour
2	Cat d-8 dozer operator	Man Hour
Crew	**Construction Equipment**	**Unit**
5	Tools	%Labor
2	Cat D-8 dozer	Machine hour
2	Cat D-6 dozer	Machine hour
2	Cat 336 excavator	Machine hour
6	Truck 20 m^3 capacity	Machine hour

4 Results

4.1 UPA methodology

With data from the example of closure a haul road and for comparison purposes between the two methods, the same labour and construction equipment rates that correspond to the Peruvian market value on the date of preparation of this document have been taken as reference.

The following table presents an estimate of costs using unit prices prepared by the UPA method, very popular in the construction industry in South America, the result obtained is USD 1,118,342, as indicated, this estimation procedure is very practical when works are carried out in a greenfield environment with multiple activities that can be executed simultaneously, allowing the contractor to reallocate their labour crews and equipment construction to other activities, assuming that they are carried out in isolation without limiting their productivity.

Table 7 Direct cost estimation with the UNIT PRICE ANALYSIS method

Item	Activity	Unit	Qty	Unit price (USD)	Cost (USD)
1.02	Cut (common material)	m^3	196,800	0.76	149,568
1.01	Spread own material	m^3	189,149	0.84	158,885
1.02	Excavation borrow material	m^3	81,064	0.81	65,662
1.03	Load borrow material	m^3	81,064	0.37	29,994
1.04	Haul borrow material d= 4 km	m^3	81,064	1.33	107,815
1.05	Spread borrow material	m^3	81,064	0.84	68,094
1.06	Load non competent material	m^3	81,064	0.37	29,994
1.07	Haul non competent material d= 3 km	m^3	81,064	1.08	87,549
1.08	Spread on waste dump	m^3	81,064	0.88	71,336
1.09	Load topsoil	m^3	146,826	0.44	64,603
1.10	Haul topsoil d= 2.5 km	m^3	146,826	0.95	139,485
1.11	Spread of topsoil e=0.40 m.	m^3	146,826	0.99	145,358
			Total direct cost		**1,118,342**

Figure 3 shows some analyses of unit prices that support the prices obtained for the estimation of the previous cost, it is observed that the productivities used for the different equipment correspond to what would be achieved if the activity is carried out in isolation, without any interaction between activities.

Assembly **01.02** **CUT (COMMON MATERIAL)**

Productivity **m3/day** MO. **1,488.0000** EQ. **1,488.0000** Direct Unit Cost by: m^3 **0.76**

Code	Resouces	Unit	Crew	Qty	Price USD	Partial U$
	Labor					
0101010005	APRENTICE	hh	1.0000	0.0054	8.08	0.04
01010100060015	DOZER CAT D8T OPERATOR	hh	1.0000	0.0054	12.09	0.07
01010200010015	LABOURER	hh	0.5000	0.0027	8.08	0.02
						0.13
	Construction Equipment					
0301010006	TOOLS	%mo		5.0000	0.13	0.01
0301090003	DOZER CAT D8T	hm	1.0000	0.0054	115.21	0.62
						0.63

Assembly **01.03** **SPREAD OWN MATERIAL**

Productivity **m3/day** MO. **1,336.0000** EQ. **1,336.0000** Direct Unit Cost by: m^3 **0.84**

Code	Resouces	Unit	Crew	Qty	Price USD	Partial U$
	Labor					
0101010005	APRENTICE	hh	0.5000	0.0030	8.08	0.02
01010100060015	DOZER CAT D8T OPERATOR	hh	1.0000	0.0060	12.09	0.07
01010200010015	LABOURER	hh	1.0000	0.0060	8.08	0.05
						0.14
	Construction Equipment					
0301010006	TOOLS	%mo		5.0000	0.14	0.01
0301090003	DOZER CAT D8T	hm	1.0000	0.0060	115.21	0.69
						0.70

Figure 3 Analysis of unit prices of some activities

4.2 All in methodology

Closure activities, by their nature, are carried out in a brownfield environment and by individual components (pits, pads, waste dump, tailings dams, haul roads, etc.), especially in the phase of progressive closure when a single component is rehabilitated, such as the haul road of our example, this localized work does not allow the contractor to reassign its crews to other activities and must be approached taking into account the interaction of the activities proposed for the closure of the component.

The procedure proposed to take this interaction into account consists precisely in analysing the development of the work and defining the workforce and basic construction equipment necessary for the execution of the closure work and estimating its daily price. The following table presents the calculation of the daily cost of the estimated base earthmoving crew assuming the productivities of the key equipment for the closure of the haul road in our example.

Table 8 Calculation of the daily cost of the earthmoving crew for Closure a Haul Road

Crew	Labour	Unit	Man Hours	Price	Partial
5	Apprentice	Man Hour	40	8.08	323
5	Laborers	Man Hour	40	8.08	323
6	Truck operator	Man Hour	48	10.92	524
2	Excavator operator	Man Hour	16	12.09	193
2	Cat d-6 dozer operator	Man Hour	16	12.09	193
2	Cat d-8 dozer operator	Man Hour	16	11.31	181
			176		**1,738**
	Construction equipment	**Unit**	**Machine Hours**	**Price**	**Partial**
5	Tools	%Labor	0.05	1738.4	87
2	Cat d-8 dozer	Machine hour	16	115.21	1,843
2	Cat d-6 dozer	Machine hour	16	80.07	1,281
2	Cat 336 excavator	Machine hour	16	84.09	1,345
6	Truck 20 m³ capacity	Machine hour	48	36.44	1,749
			96		**6,306**
		Unit Cost by day USD:			**8,044**

The basic crew is understood to be the one that will allow the contractor to meet the peak of the work without difficulties, knowing that some equipment could inevitably be underutilized, the daily cost of USD 8,044 could be adjusted including a differentiated rate (minimum hours) for excavators , which, as shown in Table 4, have a fairly low usage time, this exercise will surely be carried out by the contractor but already in the offer phase of its services.

If the estimated time because of the identification of the critical path is reasonable 203 days in our example, the estimated cost for the closure of the haul road results in USD 1,633,005 as presented in table 9.

Table 9 Closure cost estimate by number of work days

Closure Component	Daily Cost USD	Construction Days	Total Cost USD
Haul Road	8,044	203	1,633,005

This estimated cost is 46% higher than that estimated by the unit price analysis (UPA) method and is within the range of differences found by mining titleholders between the estimates made by consultants versus the real closure cost in the Peruvian experience.

5 Conclusion

Utilizing an example of real data from a local experience, it is possible to demonstrate that the use of estimation methodologies different from those conventionally used by consultants in Peru (and in South America), UPAs, can account for differences in estimations of real costs incurred in the construction phase and those provided by consultants in the study phase.

The cost estimation methodology, grouping the related and interdependent activities based on a key or critical productivity, represents with a better approximation the real costs that the contractor would incur by mobilizing to the work crews of labour and equipment in sufficient quantity to meet the peak of the work but in some cases due to the nature of the work, will inevitably be underutilized on the site.

This type of estimate takes into account the work execution schedule; therefore it is directly linked to the construction process and requires the participation of the company's constructability teams, achieving a more robust and accurate cost estimate.

Acknowledgement

We express our gratitude to all SRK professionals who contributed with their experience.

References

Caterpillar, Peoria, Illinois U.S.A. January 2017, Caterpillar *Performance Handbook*, pp. 1347
AACE International, Skills & Knowledge of Cost Engineering, Fifth Edition, Edited by Dr. Scott J. Amos, PE, 2004
Walter Ibañez, Costos y Tiempos en Carreteras, primera edición, MACRO EIRL, Lima Perú, Julio 2010
Costos y Presupuestos en Edificación, Cámara Peruana de la Construcción CAPECO, Lima Perú, enero 2000